

Acceptability and Feasibility of a New-Generation Alcohol Biosensor: A Mixed-Methods Evaluation in a Large Community Sample

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Abstract

Wearable alcohol biosensors offer an innovative solution for real-time alcohol monitoring, yet concerns about comfort, privacy, and social acceptability have limited their adoption. This study presents the largest real-world evaluation to date of a new-generation wrist-worn alcohol biosensor. In this study 150 healthy adults (ages 21–54) who wore the BACtrack Skyn sensor continuously for 14 days. Using a mixed-methods design, we assessed pre- and post-study feasibility and acceptability through structured surveys and open-ended responses, applying innovative machine learning techniques, including Term Frequency–Inverse Document Frequency (TF-IDF) and sentiment analysis, to capture nuanced user experiences at scale. Participants showed high compliance (median wear time: 94.66%), and 77% expressed willingness to extend device use. The device’s discreet, smartwatch-like appearance supported high social acceptability, with most users reporting easy integration into daily life even if no significant changes in alcohol consumption were observed. While some discomfort—particularly itching and sleep interference—was reported, overall comfort and usability ratings were favorable. Findings indicate that the new-generation wrist-worn alcohol biosensor is a feasible and well-accepted tool for alcohol monitoring. High compliance and positive user reception highlight its potential for real-world applications. While sensor comfort was generally positively rated, refining the device’s fit and materials could enhance wearability over extended periods. These insights contribute to the ongoing development of wearable alcohol biosensors that balance usability, functionality, and user experience.

Keywords: Alcohol biosensor, Wearable technology, Transdermal alcohol monitoring, User acceptability, Feasibility

Public significance statements

This study presents the largest real-world evaluation to date of a wearable alcohol biosensor, showing that a new-generation wrist-worn sensor can be worn comfortably and continuously for 14 days by a diverse group of adults. Participants found the device socially acceptable and easy to integrate into daily life. These findings support the use of wearable biosensors for alcohol monitoring in real-world settings and highlight their potential to inform public health and clinical interventions.

Author Note: A poster based on preliminary findings from this study will be presented at the 48th Annual RSA Scientific Meeting hosted by the Research Society on Alcohol (RSA), taking place June 21–25 in New Orleans. No other portion of the data or manuscript was disseminated publicly prior to this presentation.

Introduction

The ability to accurately and continuously monitor alcohol consumption is critical for both clinical interventions and public health efforts, yet existing methods often face challenges related to feasibility and user compliance. Considering the potential chronicity of alcohol-related disorders, there is a crucial need for enhanced monitoring and management methods. Traditional monitoring approaches, such as self-reported drinking, periodic blood tests, and breathalyzers, have limitations that make them inadequate for addressing the complex nature of alcohol-related disorders comprehensively. Self-reports of alcohol consumption suffer from recall bias and social desirability effects, while breathalyzers and blood tests only provide point-in-time measurements, requiring motivated action on the part of the user for each assessment (Ekholm, 2004; Livingston & Callinan, 2015; Norman et al., 2021; Davis et al., 2010).

Wearable biosensors, such as BACtrack Skyn have emerged as a transformative technology for health monitoring, offering real-time, objective data on alcohol consumption. Earlier transdermal alcohol sensors took the form of ankle-worn devices that, despite their utility, faced barriers to adoption. Their bulky designs had the potential to evoke stigma—particularly due to associations with legal or correctional monitoring—and users frequently reported discomfort when wearing these devices in public (Alessi et al., 2017; Ash et al., 2022; Courtney et al., 2023; Caluzzi et al., 2019; Barrio et al., 2019). Moreover, these earlier devices recorded data at long intervals—sometimes up to 30 minutes—limiting their ability to capture drinking events in real time.

Newer wrist-worn sensors represent a significant technological and social advancement providing continuous, non-invasive monitoring of alcohol content by assessing alcohol levels within sweat and insensible perspiration. These devices collect transdermal alcohol concentration

(TAC) data every 20 seconds, providing greater temporal resolution making them more viable for real-world use (Fairbairn & Kang, 2019). They overcome many limitations of traditional methods by passively and easily recording data that, while potentially not as precise as direct blood or breath measurements for assessing continuous blood alcohol concentration (BAC), can nonetheless provide valuable insights into overall alcohol consumption patterns and risk levels (Roberts & McKee, 2019, Courtney et al., 2023, Richards et al., 2023a). Additionally, their resemblance to consumer wearables such as smartwatches improves social acceptability, reduces stigma, and enhances compliance (Courtney et al., 2023). Emerging research supports their accuracy, with studies showing high sensitivity for detecting drinking episodes and acceptable accuracy in distinguishing high- versus low-risk drinking patterns (Fairbairn et al., 2025). A meta-analysis by Yu et al. (2022) further supports this utility, reporting a strong correlation ($r = 0.87$) between TAC and blood alcohol concentration (BAC) in controlled settings. These advancements in technology open promising new avenues for real-time, non-invasive alcohol monitoring in both research and public health contexts.

The adoption of wearable biosensors will ultimately depend on device features that extend beyond their capacity for accurate alcohol use detection, including their design, usability, and social acceptability. Fairbairn & Bosch (2021) highlight that while new-generation biosensors promise improved accuracy and real-time monitoring, widespread adoption will hinge on further reducing error rates, enhancing data synchronization, and addressing social concerns related to privacy and stigma. The Skyn biosensor, developed by BACtrack, is a discreet device worn on the wrist, with its sensor positioned below the wrist to monitor alcohol levels through perspiration in near real-time. Its resemblance to mainstream wearable technology, such as fitness trackers, makes it socially acceptable and less stigmatizing, encouraging user compliance

(Courtney et al., 2023). Privacy concerns remain significant, as users worry about social perceptions of these wearables (Courtney et al., 2023). Practical considerations, including comfort, usability, and integration into daily life, will also play a key role in sensor uptake. Challenges such as battery life, data syncing reliability, and durability must also be addressed to ensure the device meets user needs over the long term (Merrill et al., 2022). The latest generation of wrist-worn transdermal biosensor addresses these issues with a discreet, smartwatch-like design that reduces stigma, enhances social acceptability, and improves comfort for extended wear, facilitating compliance and reliable data collection (Barrio et al., 2019; Rodríguez & Russell, 2023; DiMartini et al., 2023).

However, our understanding of the acceptability and feasibility of alcohol monitoring via new-generation transdermal sensor is still in its early stages. Many previous studies on wearable biosensors have been constrained by small sample sizes (ranging from 11 to 36 participants), limiting the generalizability of findings and their ability to encompass the diversity of user experiences necessary for drawing robust conclusions (Caluzzi et al., 2019; Richards et al., 2023a; Courtney et al., 2023). Furthermore, much of this research has featured controlled settings or short timeframes (e.g., less than one week; see Brobbin et al., 2022). Critical factors such as diverse social contexts, daily activities, and user fatigue, all of which significantly influence device performance and user engagement in everyday settings, have yet to be explored (Rosenberg et al., 2023; Caluzzi et al., 2019). In addition, prior research often relied primarily on structured surveys or binary satisfaction measures (Wang et al., 2021; Alessi et al., 2017) or coder-derived thematic qualitative analysis (Brobbin et al., 2024, Caluzzi et al., 2019). While these approaches provided valuable initial insights into the feasibility and user perceptions of earlier-generation alcohol biosensors, they are limited in capturing the nuanced, real-world

experiences of participants. For instance, structured surveys and binary measures may oversimplify complex user attitudes, while coder-derived thematic analysis is subject to interpretive bias and lacks consistency across studies. In sum, we currently lack a clear view of new-generation transdermal alcohol sensor feasibility and acceptability under real-world use conditions.

The Current Research

This study evaluates the social acceptability and practical feasibility of the BACtrack Skyn transdermal biosensor through a mixed-methods approach. To this end, we engage a large community sample (N=150) over an observation period spanning two weeks. The two-week period enables the analysis of issues related to longer-term comfort, technical reliability, stigma perception, and sustained engagement. Through the analysis of use patterns in a relatively large community sample, we explore the extent to which acceptability and feasibility ratings generalize across a diverse participant pool, as well as where they are impacted by demographic and individual-level factors. We examine both pre-wear impressions and post-wear experiences, offering insights into how initial expectations regarding social acceptability, stigma, and usability evolve over time. Finally, we incorporate computationally-based qualitative methods, including machine-learning based analysis of open-ended participant feedback, to provide a richer, more nuanced understanding of user perceptions. The specific aims of the current research are as follows: (1) evaluate the user acceptability of the BACtrack Skyn biosensor, including via standard survey indexes as well as via in-depth analysis of open-ended user responses; (2) assess the compliance and practical feasibility of integrating the device into daily life during a two-week observation period, as well as the impact of Skyn on normative behaviors;

(3) analyze individual differences in user perceptions and compliance, exploring demographic and personal factors that influence device adoption and sustained use.

Materials and Methods

Participants

All study aims and hypotheses are pre-registered at <https://osf.io/cph25/>. A sample of 150 regular drinkers was recruited, aged 21-54 years (mean age = 24.5, SD = 5.5). The sample included 82 males and 68 females. Of participants, 33 identified as Hispanic or Latino. 74 participants identified as White, 47 as Asian, 15 as Black or African American, five as American Indian/Alaska Native, one as Native Hawaiian or other Pacific Islander, and eight as multiracial. Participants were excluded if they met criteria for lifetime severe alcohol use disorder (endorsing ≥ 6 DSM-5 items or history of physiological withdrawal), or if they reported adverse alcohol reactions (e.g., facial flushing with nausea or headache), inability to tolerate moderate drinking, or if they did not report drinking at least twice per week and binge drinking within the past 30 days, or were seeking treatment for alcohol use. Exclusions also applied to those for whom alcohol was contraindicated due to medications, medical procedures, or conditions, individuals with severe mental illness, and pregnant women. Additionally, individuals with Body Mass Indexes (BMIs) outside the 18-35 range were excluded due to restrictions linked with alcohol dosing procedures used in this study (Fairbairn et al., 2019) Assuming a two-tailed alpha $< .05$, power analyses indicated our current sample provides 80% power to detect demographic effects as small as $d=0.32$ in magnitude. Participants provided informed consent in accordance with the Institutional Review Board guidelines of the University of Illinois Urbana-Champaign under Protocol No. 24-0498.

Procedure

The current study is part of a larger hybrid laboratory-ambulatory experiment designed to validate the use of new generation alcohol biosensors. For this reason, we used BACtrack Skyn a compact, wrist-worn biosensor (shipped between September 2021 and September 2024) to track alcohol intoxication, comparing its readings with breathalyzer results, which estimate BAC based on the amount of alcohol in a person's breath. The full experiment was conducted over a 14-day period, requiring participants to attend three laboratory sessions one week apart. Throughout the duration of the study, participants continuously wore the Skyn device in their everyday settings. While the broader study included various procedures to assess the functionality and reliability of Skyn, the current analysis focused on self-reported impressions during the first and last laboratory visit to assess preliminary impressions and the acceptability of the device after a prolonged wearing period in a real-life environment.

During the first laboratory visit (day 1), participants were fitted with a BACtrack Skyn transdermal wrist sensor, adjustable and available in extra-small, small/medium, medium/large, and extra-large band sizes to ensure proper fit. Participants wore Skyn on the non-dominant hand throughout study participation. After receiving Skyn, participants completed a range of questionnaires, including those assessing pre-wear acceptability perceptions (WEAR Scale), demographics and overall attitudes towards technology/wearables (see Measures).

Next, participants were oriented to ambulatory procedures involving continuous Skyn wear and prompted smartphone surveys. The Skyn biosensor transmits transdermal alcohol concentration (TAC) data via Bluetooth to a paired smartphone app. In this study, however, the app was configured for passive data collection only, and participants did not have access to the data or app interface during the wear period. Participants were instructed to remove Skyn while bathing, and also while charging the devices (every ~4-6 days), but to otherwise wear Skyn

continuously throughout the 14-day ambulatory assessment period. The field assessment period also involved prompted smartphone surveys and breathalyzer readings. Specifically, during ambulatory assessment, participants responded to three types of prompts: (1) Random Prompts: sent four times daily between 4pm and 12am; (2) User-Initiated Drinking Reports: logged by participants before taking the first sip of alcohol during a drinking episode; (3) Drinking Follow-Ups: issued at 30-minute intervals following a drinking report, prompting participants to provide breathalyzer readings and 6 follow-up survey responses for up to 3 hours. The prompts also reminded participants of the importance of continuous Skyn wear. In addition, a mid-study laboratory check-in was scheduled at day 7 of the study to provide participants with feedback on their compliance with procedures. At the conclusion of the experiment (day 14), participants completed a series of questionnaires that employed a mixed-methods approach, incorporating both multiple-choice questions and open-ended responses. These questionnaires aimed to capture insights into participants' experiences, including bracelet comfort, impact, broad acceptability, and their interest in future use (see measures). All questionnaires were administered electronically using Qualtrics. A member of the research team launched the survey on a lab computer and then left the room, allowing participants to complete the questionnaire independently and in private.

Measures

The acceptability of Skyn was measured using multiple metrics, including established measures assessing overall wearable perceptions (e.g., WEAR Scale; Bracelet Comfort Questionnaire) as well as novel questionnaires designed specifically for the sensors employed in this study (e.g., Impact and Acceptability Scale). Additional information on individual subscales and items is provided below.

Demographic and Individual-Difference Moderators

Questionnaires administered at the baseline visit assessed various participant-level factors including age, sex at birth, gender, ethnicity, and race. BMI was calculated using height and weight measurements taken at the beginning of the first study visit and applying the formula:

$$\text{BMI} = (\text{weight in pounds} / \text{height in inches}^2) \times 703.$$

Pre-Wear Perceptions and Acceptability

WEAR Scale: Items assessing initial perceptions of device acceptability were drawn from the WEAR scale (Kelly and Gilbert, 2018), a questionnaire designed to evaluate user acceptance of wearable devices. Participants answered 52 questions on a scale from 1 (Strongly Agree) to 6 (Strongly Disagree). The questionnaire included the following sub-scales: Consequences (10 items, e.g. “This device could help people”), aesthetics (7 items, e.g. “This device is stylish”), norms (6 items, e.g. “This device seems fairly common”), self-identity (6 items, e.g. “This device would enhance the wearer's image”), ergonomics (5 items, e.g. “This device seems comfortable, not bulky”), judgment (4 items, e.g. “This device is cool”), others’ reactions (4 items, e.g. “The wearer of this device would get a positive reaction from others”), and others’ thoughts (4 items, e.g. “I think my peers would find this device acceptable to wear.”) The internal consistency of the WEAR scale was evaluated using Cronbach's Alpha, resulting in $\alpha = 0.94$, indicating strong reliability. Sub-scales with two or fewer items were not considered in the analysis and are reported in the supplemental material, where the complete list of WEAR scale items is included (Table S1).

Post-Wear Comfort and Acceptability

Bracelet Comfort Questionnaire: Participants indicated their experience wearing the transdermal sensor using an adapted version of the Bracelet Comfort Questionnaire (Barnett et

al., 2017). Items in this survey are intended to assess users' physical and social experiences wearing transdermal alcohol sensors, and the questionnaire includes primary indexes of comfort across physical ("How physically comfortable was the Skyn bracelet"), and social ("How embarrassing—socially uncomfortable—was it to wear the Skyn bracelet?") domains, each of which is rated on a scale from 1 (Extremely comfortable) to 9 (Extremely uncomfortable). Additionally, participants reported their perception of the bracelet's presence ("On average, how often did you notice the Skyn bracelet while you were wearing it over the course of a day?") on a scale from 0 (Never) to 5 (Several times per hour). Participants also indicated whether or not they would be willing to wear the transdermal device beyond the end of the study ("Would you wear the Skyn bracelet for another week?"). Finally, the questionnaire included two subscales aimed at assessing *interference* caused by the bracelet in activities of daily life and more specific physical or other *effects* of wearing the bracelets (e.g., itching, sweating) on a scale from 1 (Not noticeable) to 10 (Unbearable). The internal consistency of the "effects" and "interference" subscales was evaluated using Cronbach's Alpha, resulting in values of 0.86 and 0.93 respectively, indicating good to excellent reliability. A complete list of Bracelet Comfort Questionnaire items employed in this research is included in the supplementary material (Table S2).

Reactivity and Acceptability Scale: Participants rated their experience with Skyn across three dimensions. First, they assessed the effects of sensor use, including its influence on drinking patterns (Drank much less due to the bracelet=1; No impact=5; Drank much more due to the bracelet=9) as well as its impact on drinking settings, defined as the physical location and/or social company in which alcohol was consumed (No impact=1; Moderate impact=5; Large impact=9). Second, they rated their intentions for future use (e.g., "I could see myself wearing the bracelet in my daily life"). Finally, they responded to questions about broad

perceptions surrounding acceptability (e.g., “I worry about my privacy when wearing the bracelet”; “I found wearing the bracelet to be annoying”). Participants responded to questions surrounding future use and broad perceptions on a 6 point likert scale from 1 (strongly disagree) to 6 (strongly agree). A complete list of Reactivity and Acceptability Scale items and response options is included in the supplementary material (Table S3).

Open Ended Items: To ensure items captured all elements of user experience, questionnaires administered in the final laboratory session also incorporated open ended questions in which participants were encouraged to report freely on their experiences with Skyn. These free-response items assessed physical comfort “Explain how physically comfortable was the Skyn bracelet”, social comfort “Explain how embarrassing (socially uncomfortable) was it to wear the Skyn bracelet” and their overall experience with the device “What was your overall impression? What were some of the biggest positives of the Skyn bracelet for you? What was less ideal about the Skyn bracelet?” These free-response questions can also be found in the supplemental material (Table S4).

Devices and Compliance

The device employed in this research, BACtrack Skyn, monitors TAC by detecting alcohol levels within perspiration, captured via a metric that quantifies micrograms of alcohol per liter of air ($\mu\text{g/L}$). The device measures TAC data at 20-second intervals and integrates additional sensors to monitor temperature ($^{\circ}\text{C}$) and motion (g) to verify wear. User compliance in the current study was calculated by creating a proportion of time when the device recorded a temperature of 26°C or higher and a motion value of $\geq .01$, indicating wear, over the total time it was actively collecting data.

Data Analysis Plan

The data and code behind this analysis/simulation has been made publicly available at the Open Science Framework and can be accessed at <https://osf.io/cph25/files/osfstorage>. All statistical analyses were conducted using R software (version 2023.06.1+524) and Python (version 3.12.1).

Open Ended Items and Natural Language Processing: Initial preprocessing involved cleaning the text and tokenizing sentences into individual words. Lemmatization was then applied to reduce words to their base forms (e.g., “using” to “use”), while stop words (e.g., the, it, ...) were removed to focus on meaningful content. Next, analysis of participants’ text responses to open-ended questions involved two distinct strategies, both grounded in computational methods: 1-An analysis of the *frequency* of usage of various terms within participant responses; 2-An analysis of the broad *sentiment* (i.e., positive, negative neutral) of language used in participants’ responses via machine learning algorithms.

Text from the three open-ended questions was analyzed both collectively and separately. First, Term Frequency - Inverse Document Frequency (TF-IDF; Ramos, 2003) a statistical measure used to evaluate how important a word is within a document relative to a collection of documents (corpus), was applied to analyze the frequency and importance of words in the dataset. This technique assigns higher weights to words that appear frequently in a document but are less common across the entire corpus, helping to highlight significant terms. This enabled the identification of key terms that contribute to understanding sentiment and uncovering patterns in the text data. In the second step, sentiment analysis was performed using a pre-trained BERT model from HuggingFace (NLP Town) to evaluate participants' comments on a scale from 1 (very negative) to 5 (very positive). The sentiment analysis model was refined by retraining the model with an adjusted dataset to improve classification accuracy. For instance, comments such

as "normal" or "just like another watch/Fitbit," initially rated as negative, were corrected to reflect neutral sentiment (3) based on their context in physical comfort questions. These responses were typically given to the prompt "How physically comfortable was the Skyn bracelet?" where participants had previously rated their comfort on a 1–9 scale with "didn't notice" as the midpoint, indicating a neutral experience. Additionally, phrases such as "not a problem/embarrassing at all" or "no one noticed" were adjusted to reflect positive sentiment (4 or 5) as they were typically responses to the question "How embarrassing (socially uncomfortable) was it to wear the Skyn bracelet?" In this context, the fact that others did not notice the device was interpreted as a socially positive outcome.

Individual-Difference Analyses: For the post-evaluation multiple-choice questions, responses were coded as outlined in Tables S2 and S3 of the supplemental material. A multiple linear regression (ordinary least squares) was used to evaluate associations between participant-level demographic characteristics (BMI, sex at birth, age, and ethnicity) and a range of sentiment and perception outcomes, including both pre-wear impressions and post-wear evaluations. Each perception variable was modeled separately as a dependent variable, with all demographic predictors entered simultaneously. In addition to treating BMI as a continuous variable, we conducted exploratory follow-up analyses using BMI as a categorical predictor to assess potential non-linear relationships between BMI and device perceptions. Participants were grouped into three standard BMI categories based on CDC classifications: *Healthy Weight* (18.0–24.9), *Overweight* (25.0–29.9), and *Obesity* (≥ 30.0). These categorical BMI groups were entered as predictors in multiple linear regression models for each outcome previously found to be significantly associated with continuous BMI. The Healthy Weight group served as the reference category.

Results

Feasibility and Compliance

To explore the extent to which transdermal sensor use is feasible, two participant compliance metrics were calculated: 1) Wear Time, defined as the proportion of time participants were wearing Skyn, indicated by temperature $\geq 26^{\circ}\text{C}$ and motion ≥ 0.01 , relative to the total time the device was on and collecting data. This method follows an approach that was applied and validated in our previous research (see supplemental material of Fairbairn et al., 2025), where non-wear periods were identified using a temperature threshold based on a bimodal distribution, with values $< 26^{\circ}\text{C}$ classified as non-wear; 2) Missing Data, defined as the quantity of time for which no data was recorded, indicating either device malfunction or participant non-compliance (e.g., failure to charge device). Across all participants, the device was on and recording for a total of 45,917 hours. Of this time, 39,290 hours met the criteria for wear, while 6,627 hours represented periods when the device was on but not being worn (i.e., temperature and motion were below threshold). An additional 4,482 hours reflected time when the device was off and not recording at all, classified as missing data. In total, 11,109 hours of data were not classified as wear time—either due to the device being worn improperly (but on) or being off entirely. Because missing data could result from device malfunction as well as participant non-compliance, it was reported separately and not included in the wear-time denominator. The median wear time across the 14-day assessment period was 94.66% (SD = 17.83), and missing data had a median duration of 0.28 days (SD = 2.29) per participant. In sum, compliance metrics indicate that participants wore transdermal sensors for the majority of their participation and were largely able to comply with device charging procedures.

Pre-Wear Perceptions and Acceptability

WEAR scale ratings indicated varied pre-wear perceptions among participants across different device dimensions. Overall, sub-scales results ranged from 2.10 (SD = 1.14) for ergonomics—the most appreciated aspect—to 3.29 (SD = 1.24) for self-identity, suggesting it was the least liked aspect (Scale: 1 = strongly agree to 6 = strongly disagree). The second-worst score was observed in the "other's reaction" category ($M = 2.87$; $SD = 1.15$), indicating initial concern about how others might perceive or react to individuals wearing Skyn. Analysis of average scores (Figure 1, Table S5) revealed several items with values around or above the midpoint, suggesting moderate responses from participants, particularly in regard to social perception and personalization. Notably, three of these five items relate to the self-identity category ($M = 3.29$; $SD = 1.32$), highlighting a preliminary concern among participants surrounding aspects such as personal image, group affiliation, and aspirational qualities. In contrast, responses to the statement "This device could help people" yielded an average score of 1.57 (SD = 0.85) indicating a more favorable perception of Skyn's practical benefits.

Post-Wear Comfort and Acceptability

Bracelet Comfort Questionnaire: To differentiate between general disruptions to daily functioning and specific physical symptoms caused by wearing the device, two distinct subscales were used: *interference*, assessing the impact on general life domains (e.g., sleep, mood, work), and *effects*, capturing localized physical reactions (e.g., itching, sweating, soreness) (Scale: 1 = Not at all/Not noticeable to 10 = Completely/Unbearable). Figure 2 displays average scores for both types of variables related to wearing Skyn. Figure 2 displays average scores for both variables related to wearing Skyn. Results indicate that itching ($M = 3.03$, $SD = 2.39$) and sleep interference ($M = 3.19$, $SD = 2.67$) were the most negative effects experienced by participants across the 2-week ambulatory assessment period, followed by irritability ($M = 2.67$, $SD = 2.32$)

and normal work interference ($M = 2.95$, $SD = 2.47$). Overall, all variables had mean scores below 5, suggesting that, although participants experienced some discomfort and interference, the effects were generally minimal. Additionally, participants reported an average physical comfort score of 4.88 ($SD = 1.90$; Scale: 1 = Extremely comfortable, 9 = Extremely uncomfortable; midpoint 5 = Didn't notice), indicating that, on average, they experienced minimal conscious awareness of wearing the bracelet. Social comfort was rated at 2.68 ($SD = 2.04$; Scale: 1 = Not embarrassing, 9 = Extremely embarrassing), suggesting that most participants found Skyn minimally embarrassing to wear. Presence was reported at an average of 2.47 ($SD = 1.38$; Scale: 0 = Never to 5 = Several times per hour), meaning participants noticed the bracelet approximately every few hours. When asked if they would be willing to wear the bracelet for another week, 77% of participants responded affirmatively, pointing to a generally positive experience for participants in this study with Skyn.

Reactivity and Acceptability Scale: Regarding the bracelet's impact on drinking behavior, participants' responses indicated little to no change, with a mean score of 4.61 ($SD = 1.19$; Scale: 1 = Drank much less due to the bracelet, 5 = No impact, 9 = Drank much more), suggesting that, on average, the bracelet did not lead to significant increases or decreases in drinking habits. Additionally, participants were asked whether wearing the bracelet influenced their choice of drinking environment. The average score of 2.31 ($SD = 1.95$; Scale: 1 = No impact, 9 = Large impact) - suggests that the bracelet had little impact on where or individuals with whom participants chose to drink. Figure 3 illustrates participants' attitudinal ratings on predictions for future use and broad perceptions surrounding Skyn acceptability, focusing on aspects such as comfort, privacy, usefulness, and social perception (Scale: 1 = Strongly agree, 6 = Strongly disagree). The results highlighted positive perceptions of the transdermal alcohol wrist bracelet.

Participants rated the device's practicality (use) and usefulness moderately highly, with average scores of 2.81 (SD = 1.40) and 2.82 (SD = 1.38), respectively, indicating a perceived utility in everyday life. Openness to daily use received a neutral rating of 3.27 (SD = 1.42), suggesting participants were neither strongly inclined nor opposed to integrating the bracelet into their routine. Concerns about social perception were remarkably low, with score for concerns about others' opinions being only 2.07 (SD = 1.5), indicating minimal worry about how the bracelet would be perceived by others. Similarly, scores for annoyance ($M = 2.79$, $SD = 1.52$) and privacy concerns ($M = 2.41$, $SD = 1.58$) showed that participants found the device minimally intrusive and socially acceptable. The bracelet's design was moderately rated, with an average score of 3.08 (SD = 1.53) for fitting participants' personal style, suggesting room for improvement in aesthetics. Overall, the bracelet was perceived as highly practical, socially acceptable, and unobtrusive.

Post-Wear Open Ended Responses

NLP Semantic Analysis: The TF-IDF analysis of open-ended responses (Figure 4) captured participants' social, physical, and overall experiences wearing Skyn, highlighting key topics of their interactions with the device (see Measures, Open-Ended Items). Comfort emerged as a central concern, with 'comfortable' being the most frequently mentioned word at follow-up, reflecting a predominantly positive sentiment. However, the presence of 'uncomfortable' as the second most common term suggests that comfort was not universal, as some participants encountered issues. Specific problems such as tightness, looseness, sweating, and reports of itchy rashes or irritation were raised, indicating that while many participants appreciated the bracelet's comfort, others faced challenges related to its fit and wearability. Words like 'adjust,' 'sweat,' 'mark,' and 'itchy' further underscored discomfort associated with improper fit, irritation, and the

need for frequent adjustments. Many participants noted that the device left red markings or a 'rash' on their skin or felt uncomfortable over extended periods, highlighting areas for ergonomic improvements.

Social aspects also emerged in user responses, with the prevalence of words like "uncomfortable," "strange," and "embarrass" suggesting a sense of unease when wearing the device in social settings. This indicates potential stigma or perceived awkwardness, even though the overall sentiment leaned toward positivity and acceptance.

Regarding general satisfaction, participant comments included frequent usage of terms such as "good," "comfortable," "cool," and "easy." While these terms highlight positive experiences, relatively frequent usage of terms indicating a less positive physical experience also emerged, with terms like "uncomfortable" employed by some participants. Participants noted both functional positives and areas for improvement, such as reducing the "annoying" factors and ensuring that the fit was neither too tight nor too loose.

Sentiment Analysis: Sentiment analysis was conducted for each of the three open-ended questions capturing participants' social, physical, and overall experiences wearing Skyn. Figure 5 displays Kernel Density Estimate (KDE) plots for the "Physical comfort," "Social comfort," and "Overall" prompts, which provide a smoothed representation of the probability density of sentiment scores by estimating the underlying distribution using a continuous probability function. The average sentiment score for the "Physical comfort" prompt was approximately 2.83 (SD = 0.76), indicating lower comfort levels compared to other aspects. In contrast, the "Social comfort" and "Overall" prompts had higher average scores, around 3.4 (SD = 0.94 and 0.76 respectively), suggesting that participants generally felt the bracelet was socially acceptable and had a more favorable overall experience despite some physical discomfort.

Demographic and Individual-Difference Analyses

Pre-Wear Impressions: An analysis of pre-wear impressions revealed significant associations between participant-level demographic factors and initial perceptions of the device. Male participants reported more negative perceptions across several dimensions. Specifically, compared to females, they were more likely to rate the device as rude (*Rudeness*, $\beta = -0.30$, $p = .050$), exploitative (*Exploit*, $\beta = -0.44$, $p = .010$), distracting while driving (*Distraction*, $\beta = -0.39$, $p = .030$), a health risk (*HealthRisk*, $\beta = -0.38$, $p = .040$), goofy (*Goofy*, $\beta = -0.50$, $p = .010$), and undesirable (*Undesirable*, $\beta = -0.49$, $p = .010$), all reflecting higher discomfort or skepticism toward the device. Participants with a higher BMI perceived the device as less goofy (*Goofy*, $\beta = -0.06$, $p = .010$) and less excessive in its use of technology (*OverTech*, $\beta = -0.05$, $p = .030$), indicating more favorable impressions on these dimensions. Lastly, older participants rated the device as less undesirable (*Undesirable*, $\beta = -0.04$, $p = .040$), suggesting that acceptability increased with age.

Post-Wear Impressions: After wearing the device, participants' perceptions also were shaped by various demographic and individual difference factors. Higher BMI was associated with significantly lower ratings of physical comfort, $\beta = -0.08$, $p = 0.024$, indicating that individuals with higher BMI found the bracelet less physically comfortable. BMI was also negatively associated with ratings of enjoyment of life, $\beta = -0.10$, $p = 0.016$, ability to concentrate, $\beta = -0.09$, $p = 0.032$, and social life, $\beta = -0.10$, $p = 0.015$, suggesting a greater perceived interference in these areas. Interestingly, higher BMI was associated with significantly lower reported localized soreness, $\beta = -0.11$, $p = 0.005$, indicating better outcomes on this specific discomfort-related item. However, individuals with higher BMI also perceived the bracelet as less fitting with their personal style, $\beta = -0.07$, $p = 0.021$. Additional analyses using

BMI as a categorical variable revealed several group-level differences in post-wear impressions. Participants classified as Overweight reported significantly lower physical comfort, $\beta = -0.72$, $p = .037$, and rated the device as less fitting with their personal style, $\beta = -0.82$, $p = .003$, relative to those in the Healthy Weight group. In contrast, participants in the Obese category reported significantly less localized soreness, $\beta = -1.03$, $p = .026$, indicating a better outcome on that specific item. These findings suggest that BMI classification thresholds correspond to meaningful shifts in participants' evaluations of the device, and that the impact of BMI on comfort and style perceptions may not be linear. Sex was significantly related to perceived interference with exercise, $\beta = 1.19$, $p = 0.007$, with male participants reporting more interference, suggesting the device was more disruptive to their exercise routines than for females. Additionally, older participants gave higher (i.e., worse) ratings for enjoyment of life, $\beta = 0.07$, $p = 0.024$, and social life, $\beta = 0.07$, $p = 0.046$, reflecting a perceived greater interference in these domains. No statistically significant relationships were observed between demographic factors and compliance. No statistically significant relationship was found between demographic factors and compliance.

Discussion

Results of this study provide information about the social acceptability and practical feasibility of a new-generation alcohol biosensor in real-world settings. By leveraging a mixed-methods approach, combining pre- and post-wear questionnaires with text feedback analyzed with NLP, we evaluated user perceptions, device usability, and the challenges associated with integrating such technology into daily routines. Findings highlight both significant progress made in wearable alcohol biosensor technology and the remaining challenges that must be addressed to optimize its adoption and efficacy.

A critical factor influencing the uptake and eventual utility of wearable biosensors is their social acceptability. New-generation wrist worn transdermal devices, with their smartwatch-like designs, represent a notable improvement in specific domains over earlier ankle-worn models, which were linked with stigma and discomfort (Courtney et al., 2023; Caluzzi et al., 2019). In the current study, pre-wear perceptions revealed concerns about how the Skyn device might be perceived by others. Specifically, participants expressed moderate concerns about whether wearing the device would be socially acceptable, with some individuals worrying about potential negative reactions from peers. In contrast, post-wear impressions tended to show low levels of concern and broadly positive device experiences, pointing to the possibility that direct experience with the Skyn mitigates initial apprehensions. This aligns with trends in wearable technology, where devices that resemble consumer electronics are more likely to be embraced by users (Wright et al., 2021).

Participants in the current study generally found Skyn feasible for daily use, though some challenges related to comfort and wearability emerged over time. While most participants considered the device unobtrusive, some reported discomfort during daily activities, noting skin irritation, tightness, and sweat accumulation. These concerns were probably due to prolonged wear, aligning with findings from Courtney et al. (2022), indicating that extended use is linked with reports of physical discomfort. Of note, prior studies employing shorter wear periods have yielded fewer reports of participant discomfort (Ash et al., 2022; Rosenberg et al., 2021), suggesting that wear duration may play a role in user experience. Despite these reported issues, overall acceptability remained high, likely due to the device's smartwatch-like design, which made it feel familiar and socially acceptable. An additional barrier to widespread adoption that warrants consideration is device cost. Although the Skyn device offers several usability

advantages, its relatively high price point may limit accessibility for some users or populations. This high cost is largely attributable to the device's current stage of development: Skyn is currently available only to researchers, and remains under active research and development by the manufacturer. As a result, the current pricing reflects a limited market. However, given that the core sensor technology is relatively inexpensive and comparable to the low-cost fuel cells used in consumer breathalyzers, there is reason to believe that costs could decrease significantly as the product matures and enters broader markets. Participants rated Skyn favorably for its potential benefits in alcohol monitoring, with 77% willing to continue wearing it. Initially, many viewed the biosensor as a valuable tool for the broader community (e.g., "This device could help people"), which may have contributed to their openness to extended use. However, post-wear impressions revealed a shift in perspective—while participants still found the Skyn useful, they were less likely to perceive a strong personal benefit. Instead, they developed a more moderate appreciation of its value, suggesting that its perceived utility may depend on individual needs and expectations. It is possible that participants initially expected the device to provide real-time feedback on their alcohol levels, contributing to the high perceived utility reported at baseline. However, because they did not have access to their data during the study, the perceived personal benefit may have diminished over time. This interpretation highlights the importance of user expectations regarding feedback and interactivity in shaping perceived value.

Participant-level analyses of device perceptions revealed key demographic differences in comfort, usability, and social acceptability, underscoring the role of individual characteristics in shaping user experiences with wearable biosensors. Male participants had more negative pre-wear impressions, describing the Skyn device as undesirable, exploitative, and distracting. However, no evidence of such concern emerged post-wear, suggesting that real-world use may

have mitigated initial skepticism among male users. Despite this shift, males reported greater exercise interference, indicating that wrist size or movement constraints may impact usability. Addressing these issues through flexible, breathable materials may enhance comfort for active users. Additionally, Participants with higher BMIs were initially more skeptical, perceiving the Skyn as less comfortable, natural, and stylish. While post-wear ratings showed reduced concerns about soreness, higher BMIs remained associated with lower ratings for style and fit. These findings suggest a need for better size-adjustable or alternative strap designs to improve accessibility across different body types (Courtney et al., 2023). Moreover, older participants had more positive perceptions both pre- and post-wear, rating the Skyn as more acceptable, comfortable, and stylish. This trend may reflect the novelty of wearable technology for older individuals, making them more easily impressed by its features. Additionally, the perceived health benefits of such interventions may be more salient to older users, contributing to their positive reception (Wang et al., 2019). Finally, regarding privacy and social concerns, participants initially indicated worry about what others might think and further expressed moderate privacy concerns at pre-wear assessment. However, post-wear ratings indicated that these concerns were lower than expected, aligning with broader trends in wearable adoption (Wang et al., 2021; Leeman et al., 2023). These results present the possibility that real-world exposure normalizes the Skyn device, making it feel less intrusive over time.

An important question for future research is whether wearable alcohol biosensors influence drinking behavior in the absence of additional interventions. In the present study, no significant changes in alcohol consumption were observed, suggesting that merely wearing the device did not lead to immediate behavioral modifications. However, responses indicated that participants found the Skyn beneficial and easy to integrate into their daily routines, with minimal social or

practical disruptions. These findings differ from prior suggestions that self-monitoring may help reduce alcohol use, as participants in Richards et al. (2023b) believed that feedback from a biosensor could support behavior change. One potential explanation is that the outcome measures used in this study were designed to detect larger behavioral changes, and may not have been sensitive enough to capture more subtle shifts in drinking behavior. It is possible that more granular measures would have revealed smaller-scale changes. Future research should explore whether integrating real-time feedback or goal-setting features, as seen in ecological momentary intervention (EMI) studies (Wang et al., 2024), could enhance behavioral effects.

One of the strengths of this study is its large and diverse sample size, which enhances the generalizability of the findings. By including 150 participants from varied demographic backgrounds and an observation period extending to two weeks of field wear, this study captures a nuanced understanding of the Skyn device's performance in real-world settings. Advanced computational techniques, including sentiment analysis and TF-IDF, allowed us to quantify broad trends in open-text feedback and identify common patterns across a large and diverse participant pool. While these methods enhanced scalability and consistency, they are best viewed as complementary to traditional thematic analysis, which may better capture individual-level nuance. However, certain limitations should be noted. Self-reported data may be subject to biases such as social desirability and recall errors. While sentiment analysis helped quantify emotional tones in open-ended responses, it cannot fully capture the complexity of participant experiences. Moreover, the two-week observation period, though longer than many previous studies, may still be insufficient to capture long-term patterns of use and acceptance. While the study spanned all four seasons, we did not explicitly analyze the potential effects of environmental factors such as temperature or humidity on device comfort or usability. Seasonal variation may influence user

experience, but examining these effects was beyond the scope of the current investigation. Moreover, although this study includes a substantial age range and some diversity, older and middle-aged participants remain underrepresented, a common limitation in experimental alcohol research. Furthermore, this study examines only one new-generation transdermal alcohol sensor, the Skyn device. This device was selected due to its status as the only rapid-sampling, wrist-worn transdermal sensor currently widely available for research purposes. While these features make the Skyn device well-suited to research on transdermal alcohol detection, these findings might not apply to other devices.

The findings of this study offer several key insights for the design and implementation of wearable alcohol biosensors. Enhancing physical comfort should be a priority, with improvements such as breathable, hypoallergenic materials and better-fit adjustments to accommodate a wider range of users. Future iterations of Skyn could incorporate real-time feedback mechanisms, which have been shown to improve user engagement and behavioral change in other health-monitoring technologies (Richards et al., 2023b). These features could shift the device from a passive monitoring tool to an active intervention for managing alcohol use. Moreover, maintaining a socially acceptable design while leveraging user feedback—such as free-text comments on alcohol consumption—could help identify and address specific pain points, ensuring better usability and satisfaction. Given the observed differences in pre- and post-wear perceptions, developers should also consider demographic factors when refining biosensor designs. Future iterations should prioritize adjustable features for diverse body types and customization options that improve comfort, particularly for physically active users. In addition, assessing users' prior experience with or attitudes toward wearable technology may help clarify how these factors influence their pre- and post-intervention impressions of the device. By

addressing these aspects, wearable alcohol biosensors can become more accessible, effective, and widely adopted across various populations.

Conclusion

This study provides an in-depth understanding of the usability, acceptability, and challenges of wearable alcohol biosensors. Moving ahead, adjustments to these sensors will be required to address issues with physical comfort, to account for privacy concerns, and to address the needs of diverse users. Nonetheless, findings demonstrate that new-generation wrist-worn alcohol biosensors show significant promise for real-world alcohol monitoring. As the field evolves, continued innovation in design, comfort, and user engagement will be critical in ensuring that these tools become widely accessible, accepted, and impactful for both research and real-world application.

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Author contributions statements

Silvia Murgia, Ph.D., and Catharine E. Fairbairn, Ph.D., contributed to the conceptualization of the study. Dr. Murgia led data curation, formal analysis, visualization, and the preparation of the original draft. Dr. Fairbairn supported the formal analysis and was responsible for funding acquisition, investigation, methodology development, project administration, resource provision, supervision, validation, and contributed to the review and editing of the manuscript. Nancy P. Barnett, Ph.D., contributed to methodology and participated in the review and editing process. Julianne Flanagan, Ph.D., contributed to the review and editing of the manuscript. Nigel Bosch, Ph.D., contributed to investigation, methodology, software development, and manuscript review and editing.

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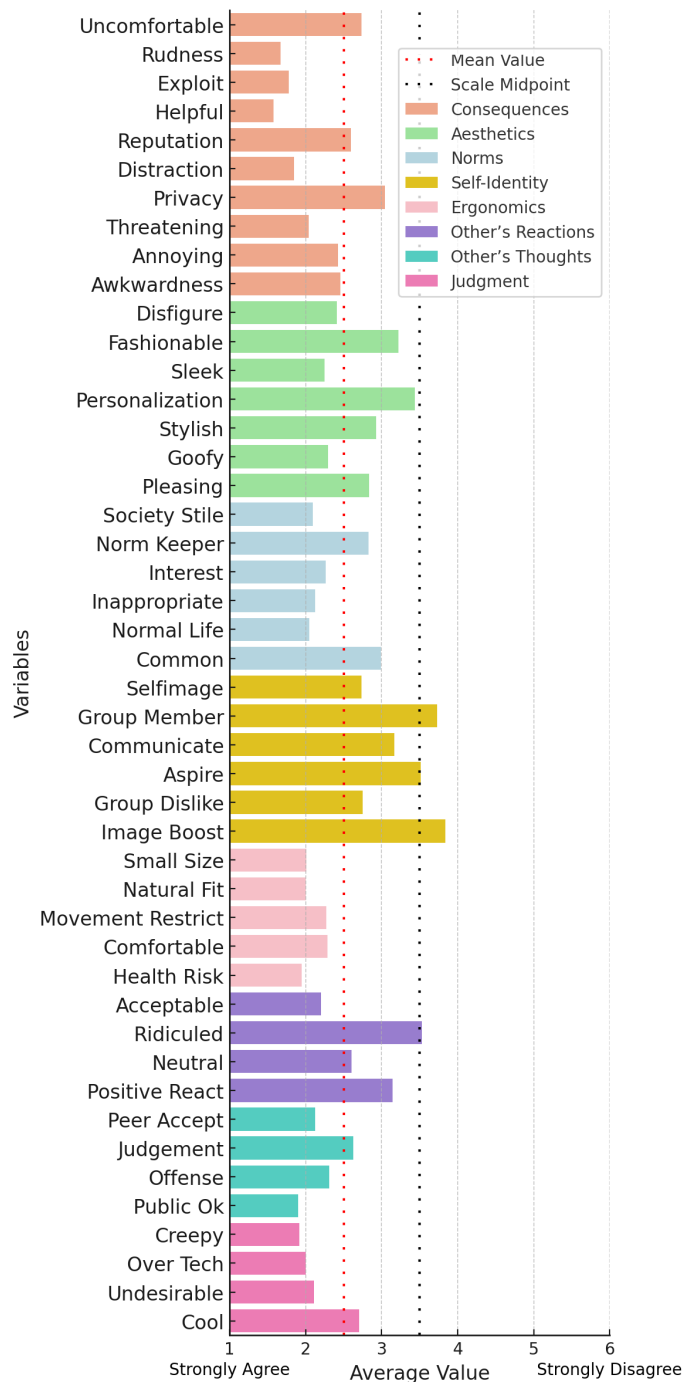
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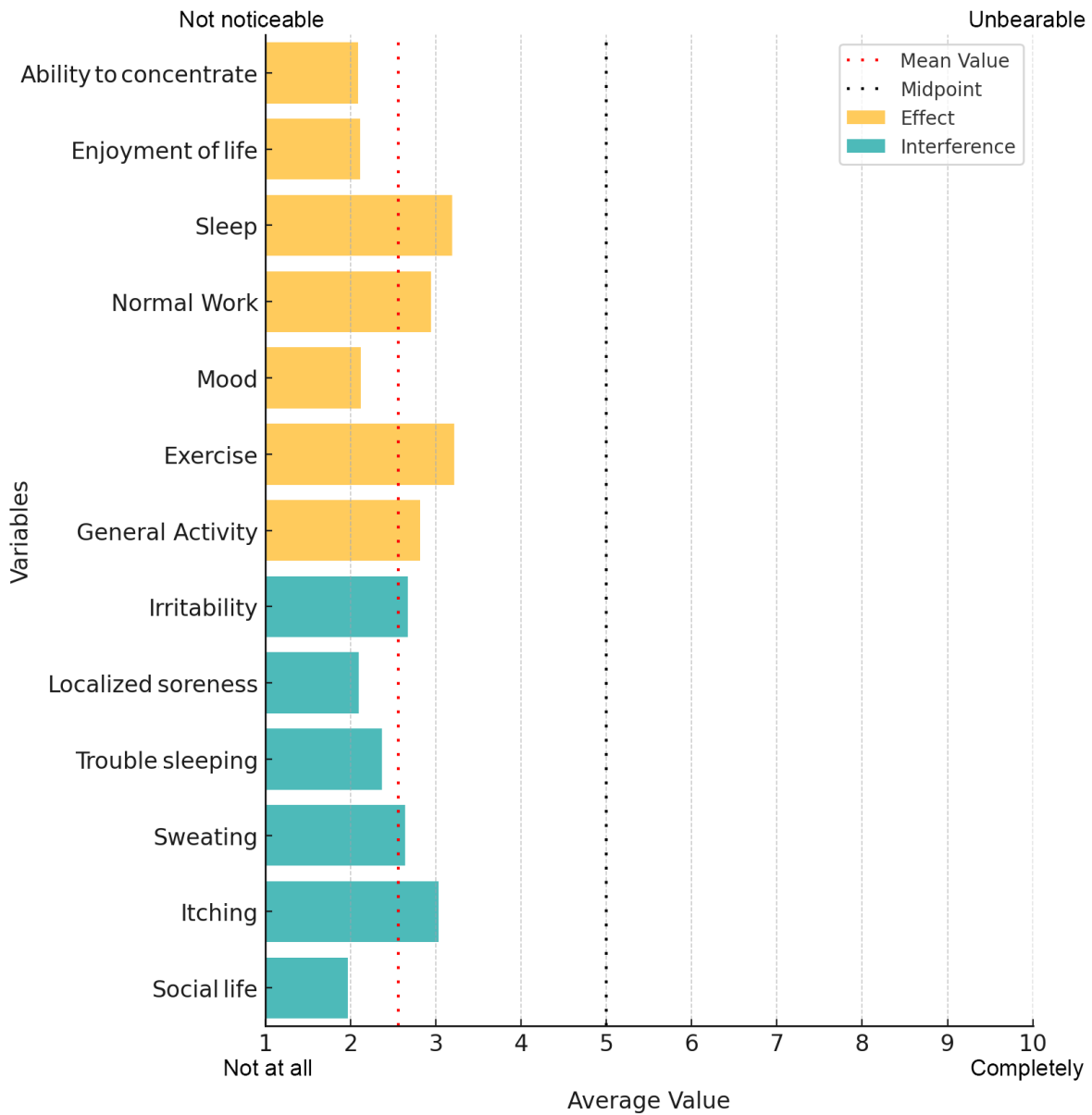
Figures

Figure 1. Pre-Wear Perceptions as Assessed via Average Item-Level scores of the WEAR scale.

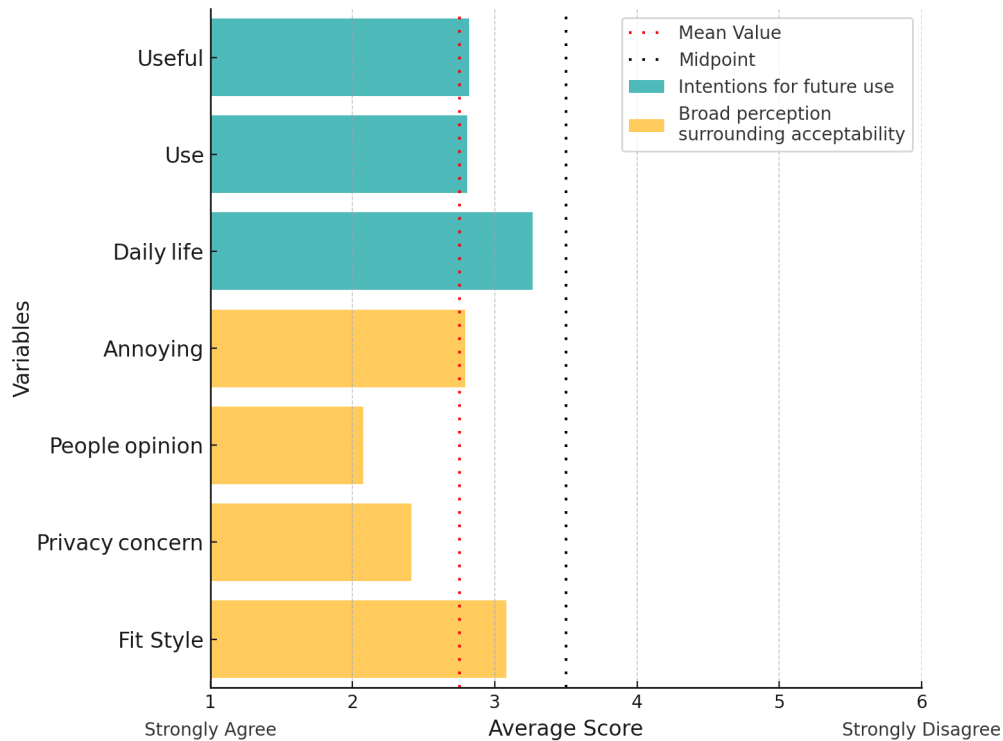


Note: Participants' ratings of their initial perception of the Skyn device were collected on day 1 using a scale ranging from 1 (Strongly Agree) to 6 (Strongly Disagree). The red dotted line represents the average score and the black line the midpoint on the scale.

Figure 2. Average Interference and Effect of Wearing the Skyn Device as Assessed via Participant Ratings.

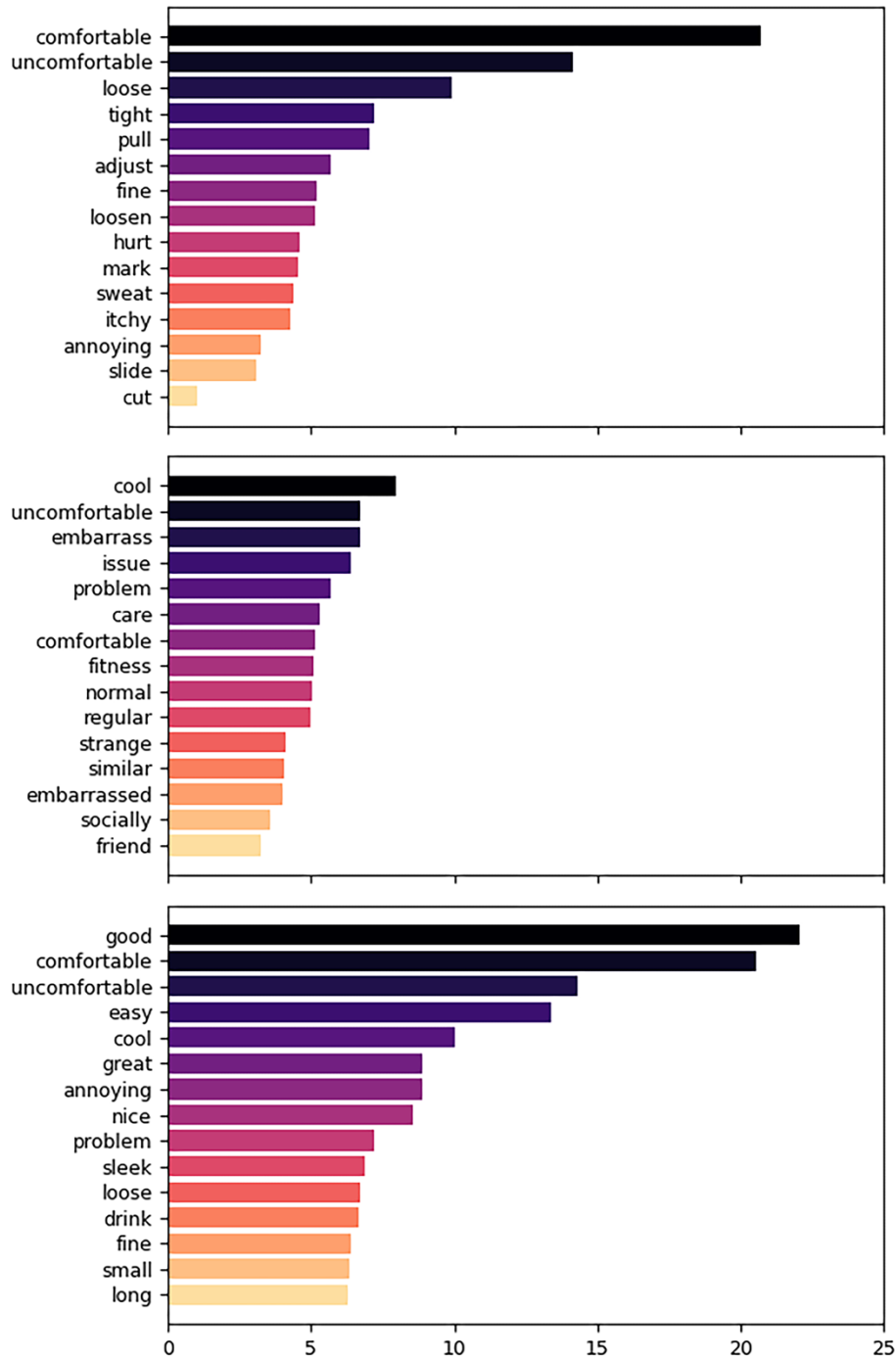


Note: Participants ratings on a scale from 1 to 10 for the interference of the Skyn bracelet in their daily life and other effects of wearing the device (Not at all = 1, Completely = 10 for interference; and Not noticeable = 1, Unbearable = 10 for the effect). The red dotted line represents the average score and the black line the midpoint on the scale.

Figure 3. *Post-Wear Predictions for Future Use and Perceptions Surrounding Skyn**Acceptability*

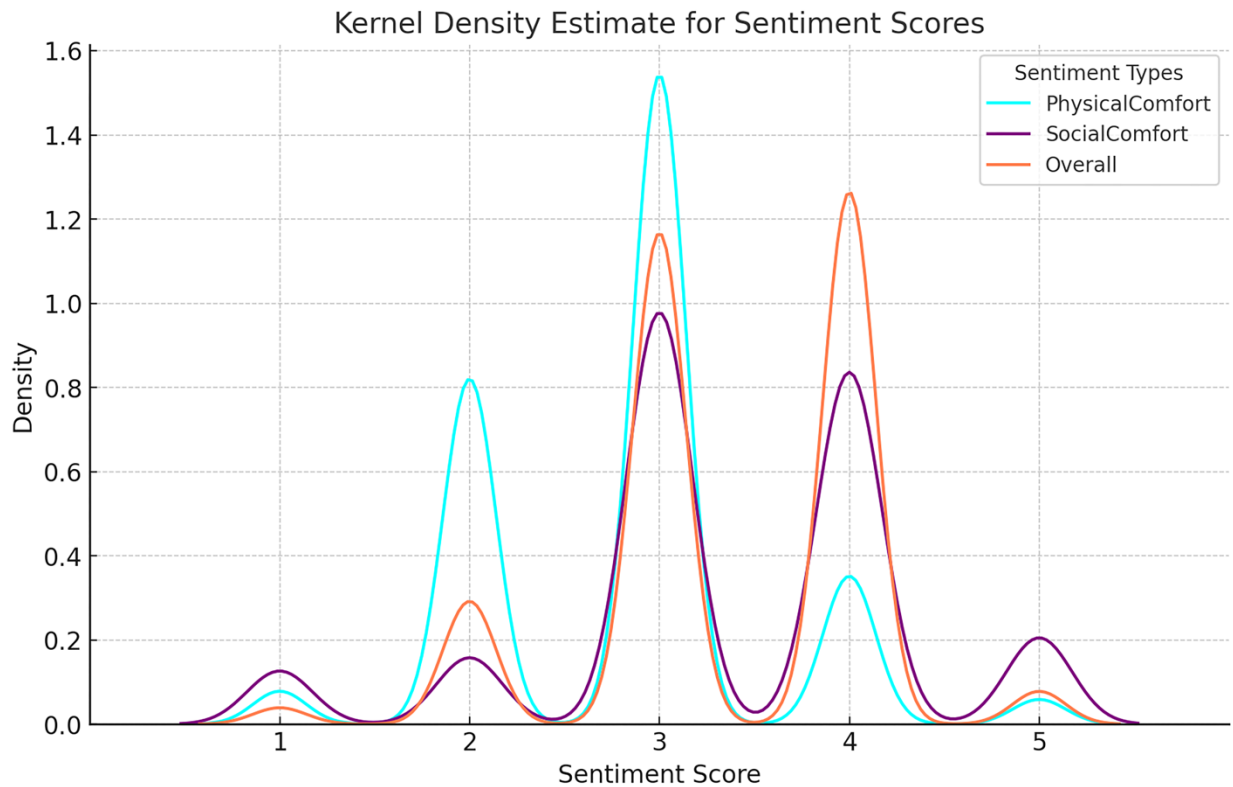
Note: Average scores of post-impression attitudes and concerns about the Skyn device, assessed through item-level averages of intentions for future use and broad perception surrounding acceptability scales. Mean scores of participants' responses to various attitudinal questions about wearing the transdermal wrist bracelet on a scale from 1 (Strongly Agree) to 6 (Strongly Disagree). These includes perceived annoyance, potential for daily use, usefulness, concerns about others' opinions and privacy, likelihood of personal use, and compatibility with personal style. The red dotted line represents the average score and the black line the midpoint on the scale.

Figure 4. *TF-IDF Analysis of Open-Ended Responses on Physical Comfort, Social Comfort, and Overall Impression.*



Note: The picture displays the TF-IDF analysis results for open feedback related to device experience. The plot represents perceptions of physical comfort, social comfort, and overall experience with the device (from top to bottom). The bar lengths indicate the importance of terms within the document(s). Higher scores represent terms that are more distinctive to a specific open-ended question relative to all the questions.

Figure 5. Kernel Density Estimate (KDE) Plots of Sentiment Scores as Assessed from Participant's open Feedback.



Note: Kernel Density Estimate (KDE) plots showing the distribution of sentiment scores for Physical comfort, Social comfort, and Overall prompts. The x-axis represents sentiment scores from 1 (negative) to 5 (positive), The y-axis represents the density of responses, providing insight into the central tendencies and variability across the three different aspects of wearing the bracelet.